National Transportation Safety Board
Office of Research and Engineering
Washington, DC 20594

RRD22LR001

MATERIALS LABORATORY

Specialist's Factual Report - Supplemental 22-032B

September 21, 2022

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A. ACCIDENT INFORMATION

Location: Arlington, Virginia
Date: October 12, 2021
Time: 4:50pm eastern daylight time
14:15 coordinated universal time
Vehicle: WMATA Metro Blue Line
Investigator: Joe Gordon, RPH-10

B. COMPONENTS EXAMINED

Remnants of a restraining rail

C. EXAMINATION PARTICIPANTS

Specialist Erik Mueller, Ph.D., P.E.
Office of Research and Engineering – Materials Laboratory Division
NTSB

D. DETAILS OF THE EXAMINATION

This report is an addendum to the *22-032 Materials Laboratory Factual Report*. A section of restraining rail found near the McPherson Square station (Washington, DC) was excised and then sent to the NTSB Materials Laboratory for additional examination.

This remnant was found during a visual track inspection conducted by MxV (then TTCI) on March 8, 2022.[1] Conducted along with personnel from WMATA, the fractured restraining rail was identified between Metro Center and McPherson Square on Track 1 and Track 2. The restraining rail in this location was a horizontal restraining rail, which is unique to the C and D line (typically in the rest of the system, restraining rail is installed in a vertical design). Inspection personnel witnessed the restraining rail did not have a flare on its start, which concerned TTCI and WMATA personnel because Track 1 is the inbound track from McPherson Square to Metro Center, and vehicle movement is in a forward direction at that location during normal operations. There had been a concern by party representatives that a wheel in a normal direction could impact the start of the restraining rail.

Figure 1 shows the section of the guard rail from the side at the outside or field corner. The majority of the surfaces were covered in a black-colored, sticky substance, consistent with material accumulated from service in a rail tunnel.

[1] MxV Rail, formerly Transportation Technology Center, Inc. (TTCI), is a subsidiary of the Association of American Railroads (AAR) that conducts railroad equipment testing and training for member railroads, headquartered in Pueblo, CO.

In the figure, the fracture surface faces towards the right. On the field corner near the fracture was a more reflective area, exhibiting some localized brown-colored spots. The reflective area was oriented parallel to the running direction of the rail head, with streak marks oriented along the rail direction. This area was consistent with an impact with a metallic component, after the dark material accumulation. The brown spots were consistent with oxidation from reactions with water after the impact or sliding event.

Figure 2 shows the fracture surface of the restraining rail, as received. This figure was overexposed in oblique lighting to demonstrate the dark-colored features on the surface. Most of the surface exhibited elongated deep undulating features, located along the base and web regions. These marks were mostly oriented perpendicular to the material cross section, with some angled orientation at the web/base transition. Closer examination of these regions showed smoothed and rounded features, consistent with melting and resolidification of metal alloys. These regions were consistent with having been torch cut.

The fracture surface was sectioned from the rail segment, along with another adjacent cross section, as illustrated in Figure 3. The fracture surface was cleaned in an ultrasonic bath of acetone, which removed most of the dark surface contamination, indicating it had been consistent with organic material. Figure 3a demonstrates the bluish-gray and dull gray colors of the torch cut region along the web, typical of steels exposed to elevated temperatures. The cross section in Figure 3b shows the change in the head geometry on the field (upper left) corner. This was consistent with material deformed and flowing over the fracture surface (upper left in Figure 3a) and the reflective area absent dark contamination on the rail head surface in Figure 1.

The head area of the fracture surface exhibited several different fracture features, distinct from those of the torch cut web and base cross sections. Figure 4 shows a closer view of the head. As shown in this figure, there were alternating bands of rougher and smoother fracture features. The head of the fracture surface was sectioned from the web, and then cleaned in an ultrasonic bath with Evapo-Rust in order to remove surface oxidation.[2] Figure 5 illustrates the sectioned and cleaned fracture surface head region, annotated to show the different fracture regions. These included two regions of crack propagation, consistent with fatigue, and two regions of overstress fracture features. The details of these fracture modes are elaborated below.

[2] Evapo-Rust is a commercially-available chelating rust stripper manufactured by Harris International Laboratories, headquartered in Springdale, AR.

Figure 6 shows an area of the head fracture surface adjacent to the torch cut region of the web. This area exhibited a relatively flat band, consistent with progressive crack propagation later determined to be fatigue. This region exhibited multiple thumbnail cracks, separated by ratchet marks, indicative of multiple crack initiation sites.

The area adjacent to the torch cut material was examined with a scanning electron microscope (SEM), as shown in Figure 7. This figure shows the multiple thumbnail-shaped fatigue cracks, exhibiting crack arrest marks concave upward, consistent with propagation from the torch cut regions into the rail head. Figure 8 is an annotated version of Figure 7, showing the general crack growth direction of the small thumbnail cracks. This region showed crack propagation for approximately 0.5 to 1.0 mm (0.02 – 0.04 in).

As shown in Figure 9, these thumbnail cracks exhibited fatigue striations, consistent with fatigue crack propagation. Figure 10 shows a closer view of the overstress region outside of the crack propagation region, further upward in the rail head. This area exhibited cleavage facets and dimpled rupture, consistent with overstress fracture in hardened metal alloys.

The most visually apparent feature in the head region of the fracture surface is the smoother textured curved band, later determined to be fatigue crack propagation. Figure 11 shows a closer view of this second fatigue region band in the head portion of the rail. This area exhibited crack arrest marks, consistent with crack propagation, and ratchet marks along the lower portions, indicative of smaller cracks coalescing into larger ones. The ratchet marks were located concurrent with pronounced rougher features along the lower (concave) edge of the crack propagation. Like with the initial fatigue region, this area exhibited striations when examined with a SEM.

Figure 12 shows the transition from the mixed cleavage overstress region to second fatigue region, shown optically in Figure 11. The area in the upper left of Figure 12 shows the fatigue propagation region, and the lower right shows the mixed cleavage overstress region. Two of the diagonally-oriented ratchet marks we located concurrently with two of the more pronounced protrusions of the overstress regions. The areas in between contained fatigue crack initiation sites.

Figure 13 shows the opposite (convex or upper) edge transition of the main crack propagation band, as examined using a SEM. This micrograph was taken prior to cleaning with Evapo-Rust, and shows some of the underlying fatigue striations, but also exhibited a thick enough oxidation layer to create charging effects in the microscope.

Figure 14 shows the same region, after the final cleaning step. This removed the surface oxidation, but also removed some of the fracture details at particular magnification ranges. The flatter, smoother region in the lower right was the fatigue crack propagation region, exhibiting crack arrest marks and fatigue striations. The more tortuous region in the upper left of Figure 14 was the subsequent overstress region. A closer view of this area is shown in Figure 15. This area exhibited cleavage facets and dimpled rupture, consistent with overstress fracture in hardened metal alloys.

The fracture features of the rail head, annotated in Figure 5, were consistent with the rail having been torch cut prior to any crack initiation and propagation in the head. The web and base exhibited features consistent with much of the rail cross section having been torch cut. There was an initial fatigue crack region, which had initiated at multiple sites along the edge of the torch cut gap in the web. A fatigue crack propagated for a small (0.5-1.0 mm) depth before a large overstress jump occurred. This did not completely fracture the rest of the rail head, and a second band of fatigue cracks initiated at another series multiple sites. The remainder of the rail head fractured in overstress from a final stress input.

Submitted by:

[redacted]
Materials Research Engineer

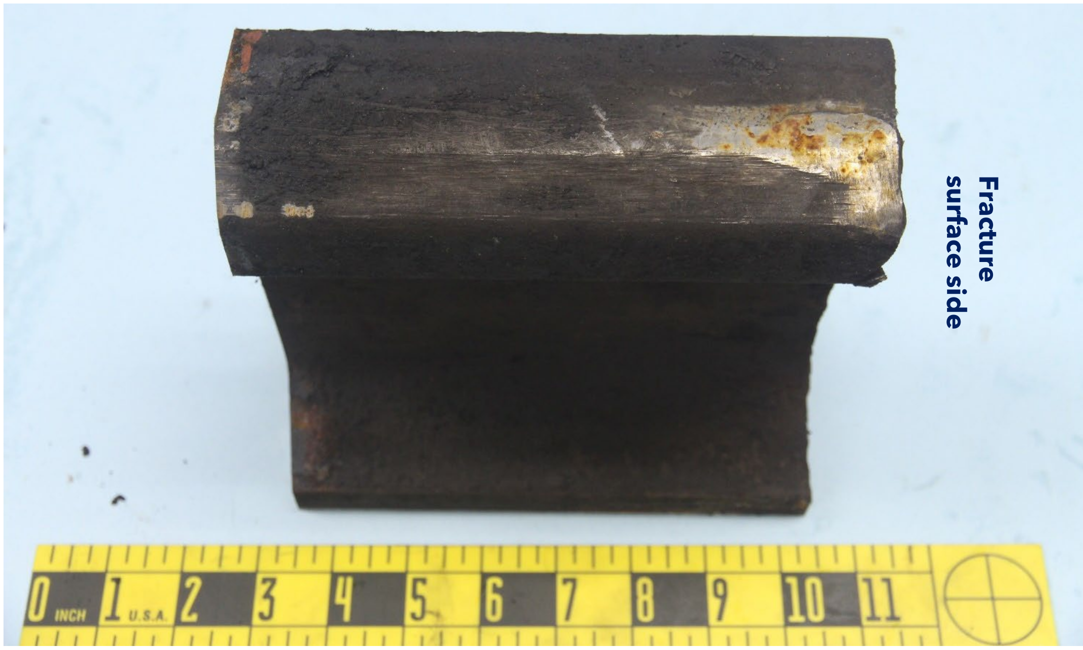

Figure 1. View of the sectioned mount remnant and fractured stud, as received.

Figure 2. View of the fracture surface of the guard rail section, as received (overexposed to show the darker fracture features).

Figure 3. View of (a) the sectioned and cleaned fracture surface of the guard rail, contrasted with (b) a cross section through the rail, showing the rail profile.

Figure 4. Closer view of the restraining rail head fracture surface, after initial cleaning.

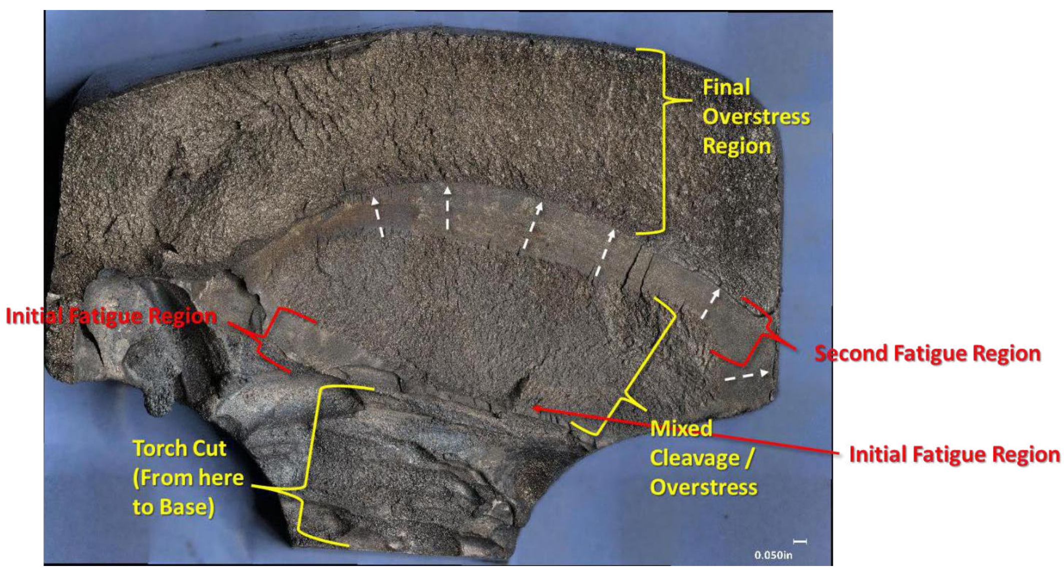

Figure 5. The cleaned head fracture surface, annotated to show various regions.

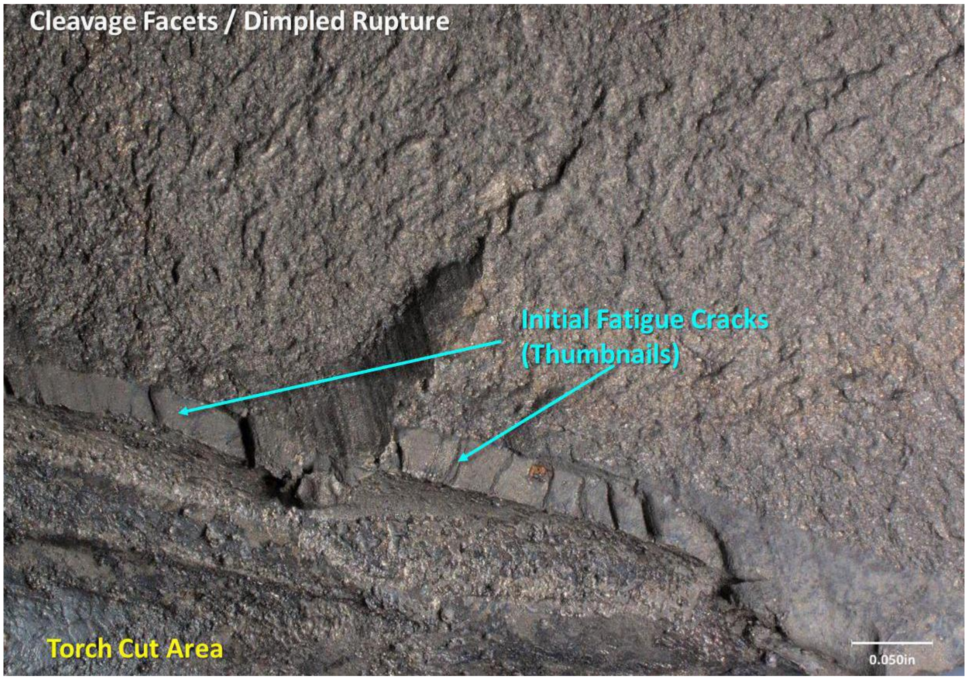

Figure 6. The initial fatigue thumbnail cracks near the torch cut web section.

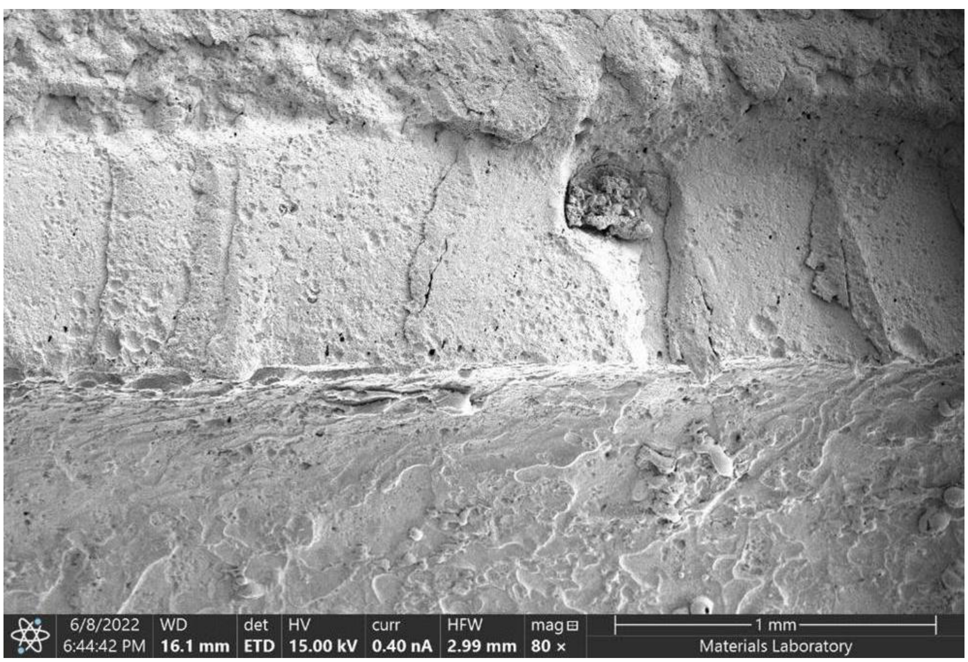

Figure 7. SE micrograph of fatigue cracks near the torch cut web.

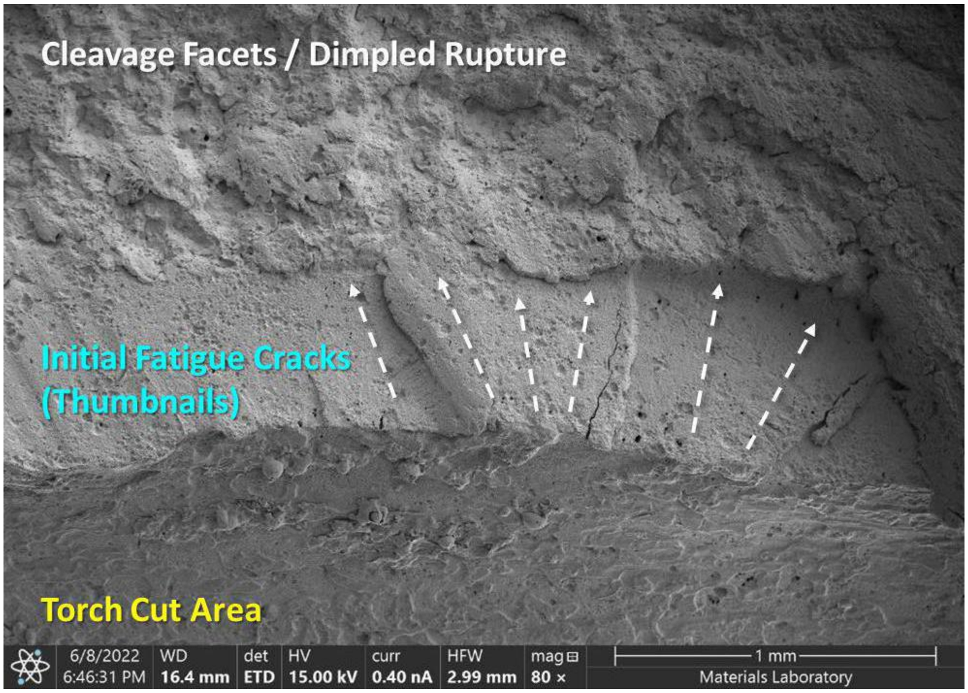

Figure 8. SE micrograph of the initial fatigue region near the torch cut, annotated.

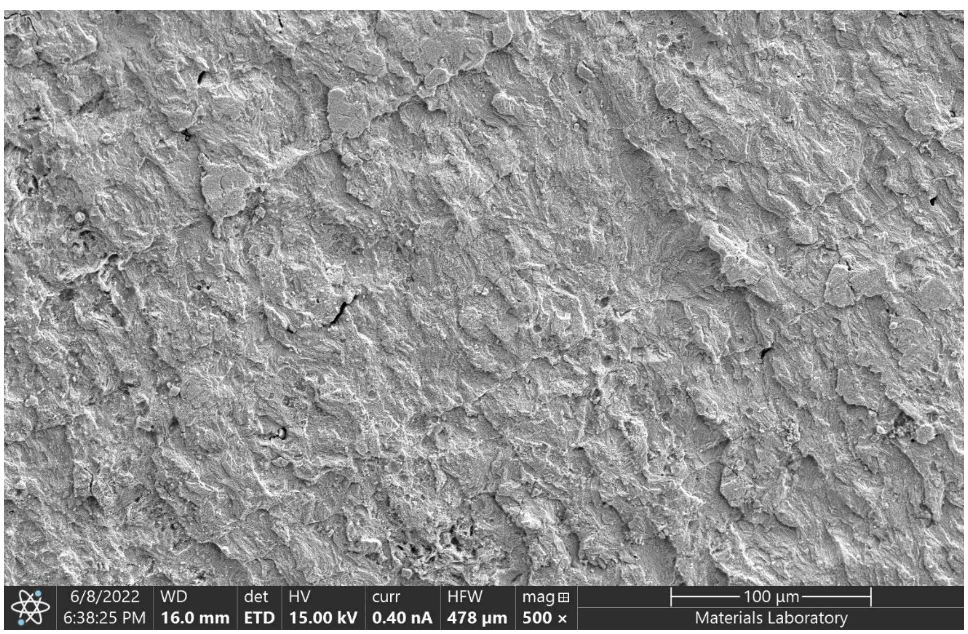

Figure 9. SE micrograph of fatigue striations on the initial fatigue region of the rail fracture surface.

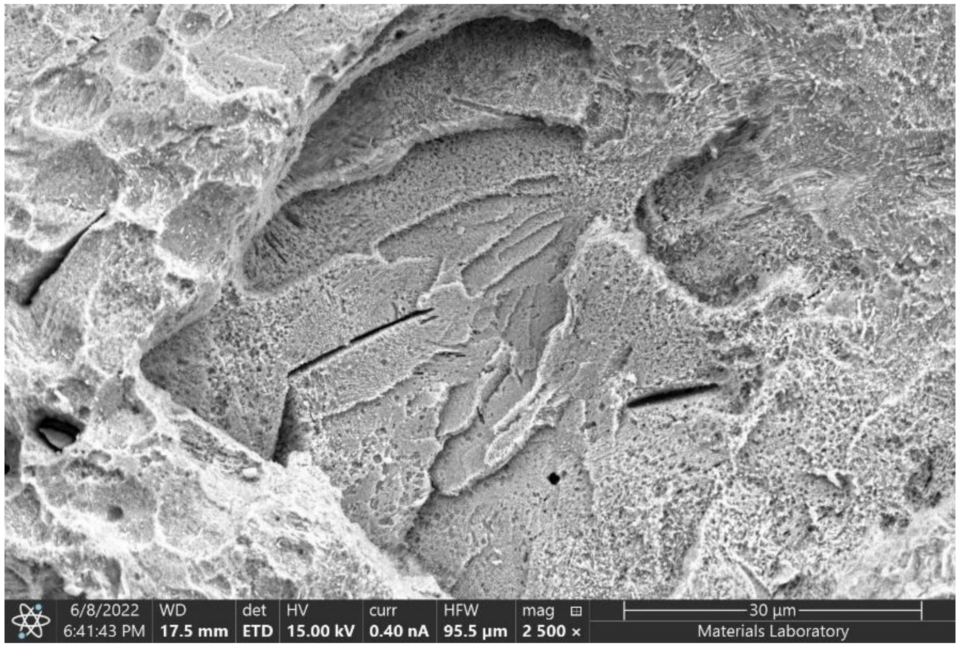

Figure 10. SE micrograph of a typical cleavage facet remnant from Figure 12.

Figure 11. View of the right side of the intermediate fatigue band region, showing ratchet marks and crack arrest marks.

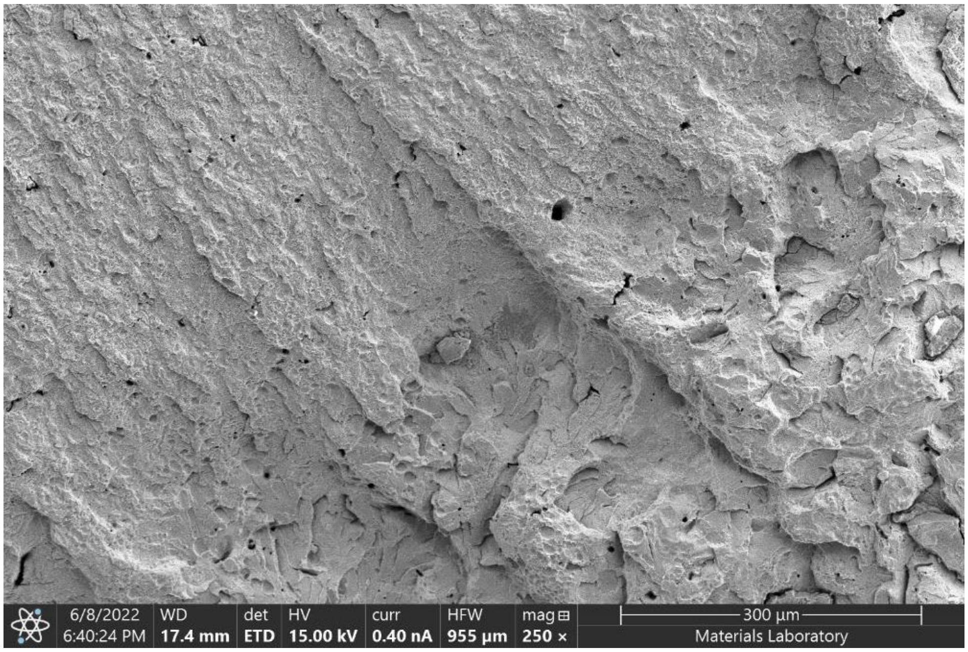

Figure 12. SE micrograph of the initial transition from overstress to the second fatigue region.

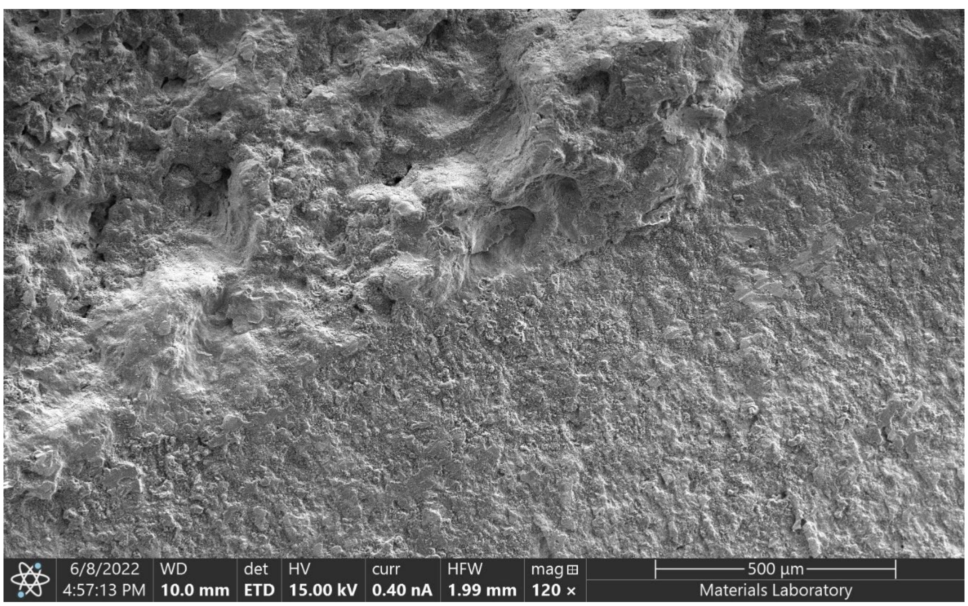

Figure 13. SE micrograph of the transition from the second fatigue region to final overstress region of the rail head (before final cleaning).

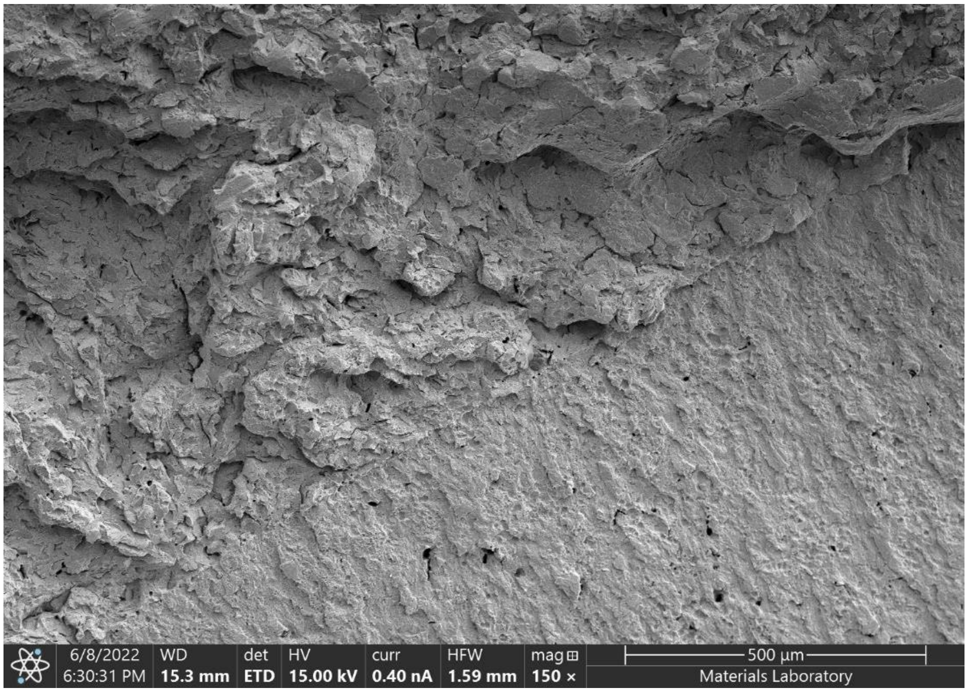

Figure 14. SE micrograph of the region in Figure 13, after cleaning.

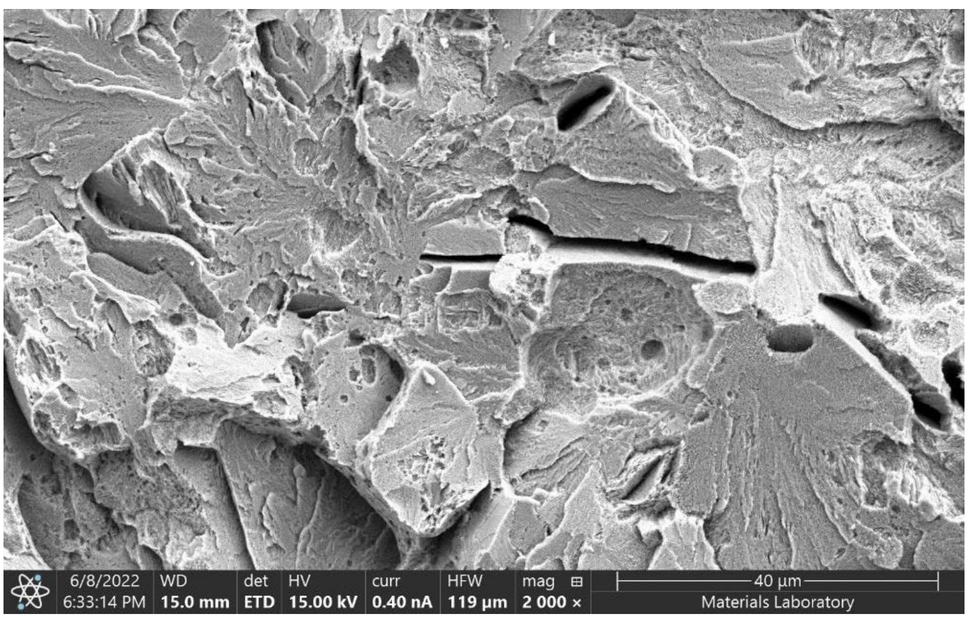

Figure 15. SE micrograph of a cleavage facets and dimpled rupture in the final overstress region from Figure 14.